Origins of the Digital Antenna Array Theory

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***Abstract*— In this paper the origins of the digital antenna array theory are presented.**

Keywords— multichannel estimation; digital antenna arrays (DAA)

I. INTRODUCTION

Smart antennas (or digital antenna arrays) have a wide spreading in radars and communication means. Hower, the history of origin of the digital antenna arrays theory has no unequivocal interpretation till now. The report presents the results of the researches of the author, directed to find out the history of the digital antenna arrays theory as the history of a multichannel estimation theory.

II. THEORY

The theory of the digital antenna array (DAA) started to emerge as a theory of multichannel estimation. Its origins go back into methods developed in the 1920s that were used to determine direction of the arrival of radio signals by a set of two antennas based on the phase difference or amplitudes of their output voltages. Thus, the assessment of the directions of arrival of a single signal was conducted according to pointed-type indicator readings or according to the Lissajous curves, drawn by beam on the oscilloscope screen. An example is publications of H.T Friis [1, 2] (fig. 1).

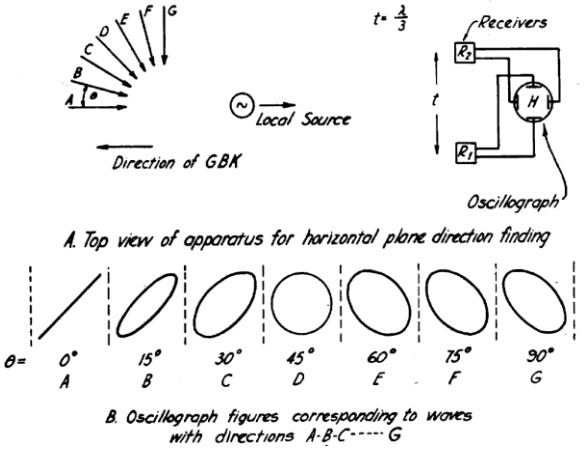

Fig. 1. Double detection receivers [1].

The simplest search of patents in the Internet reveals several dozen of patents that using similar technical solutions for radars, radio direction finders, navigation aids. It is, for example, so-called phase-comparison direction finder (US Patent №2423437, fig. 2) or amplitude-comparison direction finder (US Patent №2419946).

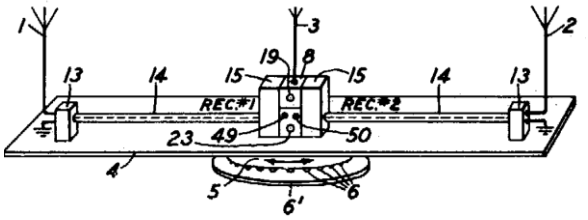

Fig. 2. Direction finder (US Patent №2423437).

In the late 1940s this approach caused the emergence of the theory of three-channel antenna analyzers that provided the solution to the problem of signal separation of air target and "antipode" reflected from the underlying surface by solving system of equations which were obtained with the help of complex voltages of three-channel signal mix (see [3]). In mentioned reference, according to the classification of Varyukhin V.A., used in the book [4], there was a phase multichannel analyzer, which provided the resolution of signals from two sources by elevation angle. The results of experimental measurements with the help of equivalent three-channel device were published by Frederick Brooks in 1951 [5].

The growing complexity of solving such radar challenges, as well as the need to implement effective signal processing by the end of the 1950s predetermined the use of electronic computers in this field. For example, in 1957, Ben S. Meltont and Leslie F. Bailey published a very significant article in this field [6], where authors offered options of implementation of algebraic operations for signal processing with the help of electronic circuits, their equivalents, with the aim to develop signal correlator on the base of certain analogue computer. In fact, this article set a precedent of symbiosis of receiving system and special computer for signal parameter assessment and consequences of such combination were not long in coming.

The replacement of analogue computer facilities by digital technologies three years after in 1960 was embodied in the idea of using high-speed computers to solve directional finding problems, initially to locate earthquake epicenter. B. A. Bolt was one of the first who implemented this idea in practice [7], he has developed a program for IBM 704 for seismic direction finding based on the method of least squares. Almost

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simultaneously a similar approach was used by Flinn, research fellow of the Australian National University [8].

Despite the fact that in the mentioned experiments the interface between sensors and computer was implemented with the help of data input cards, such decision was a decisive step on the way of the appearance of the DAA. Then, there was only to solve the problem of direct digital data, obtained from sensing elements, input into computer, excluding the stage of preparation of punch card and operator assistance as a surplus link.

At the same time, the solution of the problem of improving the processing of information obtained from sensor array could be reduced to software development for the computer that is integrated with them. Since then, similar decisions could be replicated in any radio application.

Apparently, it was Polikarpov B.I. who first drew attention to the potential possibilities of multichannel analyzers in the USSR. In his paper "On some possibilities of application of independent channels of signal reception and the use of electronics and computer technologies to improve antijamming capabilities and resolution characteristic of radar measurement" published in the collection of studies [9], he discussed analyzers of phase type with equal or multiple distances between phase centres of receiving channels, the outputs of which are subjected to correlation processing and angular coordinates of signal sources are determined by computers. The paper shows the principal possibility of signal sources resolution with an angular distance less than aperture angle of the antenna system.

However, a specific solution to the problem of super-Rayleigh resolution of the emission sources was proposed by Varyukhin V.A. and Zablotskiy M.A. only in 1962, they invented corresponding method of measuring of directions to sources of electromagnetic field [10]. This method was based on the processing of information contained in the distribution of complex voltage amplitudes at the outputs of amplitude, phase and phase-amplitude multichannel analyzers and it permitted to determine the angular coordinates of sources within the width of the main lobe of the receiving antenna system.

Further Varyukhin V.A. developed a general theory of multichannel analyzers, based on the processing of information contained in the distribution of complex voltage amplitudes at the outputs of the antenna array. This theory considers methods for determination of the angular coordinates of sources depending on angular distances between them, phase and energy relationships between the signals, as well as functional circuits of devices, that are subject of theoretical conclusions. Measurement of source parameters is performed by direct solving of systems of high-order transcendental equations, describing response function of a multichannel analyzer. The difficulties arising in the solution of transcendental systems of high-order equations were overcomed by Varyukhin V.A. with the help of "separation" of unknown variables, where determination of angular coordinates reduces to the solution of two or even one equation, and determination of complex amplitudes comes to the solution of linear systems of equations of N^{th} order [11].

An important milestone in the recognition of the scientific results of Varyukhin V.A. was the defence of his doctor of science dissertation, held in 1967. A distinctive feature of developed by him theoretical foundations is the maximum automation of the process of assessment of the coordinates and parameters of signals, whereas an approach based on the generation of the response function of seismic multichannel analyzer and assessment of its resolution capabilities on the basis of visual impressions was just arisen abroad at that time.

What is meant here is a Capon method and developed further MUSIC, ESPRIT methods and other projection methods of spectral estimation.

The originality of the main theoretical achievements of the scientific school of Varyukhin V.A., obtained by him and his learners against theoretical methods of spectral estimation developed abroad, is preserved to this day due to the maximum consideration of specific features of the analytical description of the response function of multichannel analyzer, including function that is based on the fast Fourier transform. We are talking about reducing the problem of super-Rayleigh signal resolution by the outputs of secondary receiving channels to solving an algebraic equation of M degree, where M is the number of sources, the possibility of unbiased estimation of signal parameters, determination of an unknown number of signal sources and other important aspects.

III. Conclusion

Of course, it is ungrateful to make a conclusion about the priority and importance of various alternative scientific approaches in the process of development of a general theory of the DAA, taking into account classified nature of the majority works and the lack of the possibility to study scientific heritage of that time, even taking into account Internet. Proposed here historical journey only slightly raised the veil of time over the true development of scientific research and its main aim was to point general niche and time frame of the inception of the theory of multichannel analysis through the lens of historical background. A detailed presentation of the historical stages of development of the DAA theory deserves standalone consideration.

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